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PRELIMINARY RESULTS ON THE EVALUATION OF A FLEET POST-TRAINING PERFORMANCE EVALUATION TECHNIQUE

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1. Enclosure (1) is an evaluation of four different performance estimators relative to a criterion measure of absolute technician performance. The technicians were involved in fleet electronic maintenance activities in one of the ratings - EM, ET, FT, IC, RD, RM, ST, and TM.

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Principal Investigator: Paul P. Foley

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NAVAL PERSONNEL RESEARCH AND DEVELOPMENT LABORATORY
WASHINGTON, D.C. 20390

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FOREWORD

This research effort is being performed with the support of the Personnel and Training Research Programs Office, Office of Naval Research, under Project Order No. 2-0046, Work Unit Number NR 150-336 entitled PERSONNEL TECHNOLOGY: Relating Individual Performance Effectiveness to Unit and Ship Effectiveness. This is the first in a series of reports on the analysis of the performance data collected in the course of the project.

Appreciation is expressed for the cooperation and assistance provided by Commander, Cruiser-Destroyer Force, Atlantic Fleet, Commander, Cruiser-Destroyer Force, Pacific Fleet, and Commander, Cruiser-Destroyer Flotilla NINE for providing the ships and men that took part in the data collection effort of this project.

The assistance of Dr. Arthur I. Siegel of Applied Psychological Services, Inc., Wayne, Pennsylvania, is also appreciated for providing some of the computer programs which were employed in analyzing the performance related data.

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SUMMARY AND CONCLUSIONS

Problem

The advent of a more streamlined Navy operating under reduced manning levels and heightened operational requirements imposes the need for accurate human-performance evaluation of ship personnel systems. On the personnel systems level, electronic technician reliability measurement is a necessary and integral part in the evaluation of particular combat systems of which technicians are components. The objective is then to develop and evaluate human-performance reliability estimates so as to be able to effectively alter the personnel system in order to maximize the overall performance of the system. The purpose of this project is to validate the utility and effectiveness of a unique human performance measurement procedure developed under a prior Office of Naval Research project and designed to improve upon existing performance measuring techniques in a systems environment.

Background and Requirements

Human reliability performance estimation can be accomplished by considering the individuals being evaluated as components of a personnel system. This consideration allows the use of much of the theory already applied to equipment reliability estimation to be adopted to human-performance estimation. After this theory is applied to evaluate the performance of human components in a personnel system, appropriate combinations of the individual performance estimators will provide a performance or reliability estimate of the personnel system itself.

In order to improve upon existing performance estimators of the human component in a personnel system, Dr. Arthur I. Siegel and his associates of Applied Psychological Services, Inc., Wayne, Pennsylvania, developed fleet post-training performance criteria for electronic maintenance personnel with the support of the Office of Naval Research. The cumulation of these efforts resulted in the development of unique human performance measurement techniques, closely allied with equipment reliability estimation techniques. Siegel also developed procedures for combining the technician performance estimates in appropriate ways in order to estimate team, ship or squadron performance.

An outgrowth of the prior research effort was the suggestion that the techniques be introduced on a limited basis to determine how they may be modified or elaborated upon. The Naval Personnel Research and Development Laboratory is presently validating the utility and effectiveness of these techniques. The main technical objectives of this validation effort are to determine the validity of the performance

measurement techniques, identify the restrictions or modifications required in order to maximize their validity, and to comment on the statistical properties of those techniques as related to their effectiveness in an operational context.

Approach

In order to realize an efficient and timely data collection effort, optical scanning instruments were utilized similar to those employed by Applied Psychological Services in prior research efforts.

The main data collection instruments were:

1. Personnel Identification Information Forms (PIIF) - this form records demographic data on the technician being evaluated.

2. Technical Proficiency Checkout Form (TPCF) - this form records the level of technical complexity at which a man is able to perform without direct supervision.

3. Job Performance Questionnaire (JPQ) ANSWER SHEET - this form records supervisory estimates of the total number of a technician's uncommonly (ΣUE) and ineffective performances (ΣUI) that the supervisor has observed during a specified time period.

On each of the above instruments an individual in one of the electronic maintenance ratings EM, ET, FT, IC, RD, RM, ST, and TM was evaluated by his supervisor. On the basis of the total number of uncommonly effective (ΣUE) and the total number of uncommonly ineffective (ΣUI) incidents of performance recorded on the Job Performance Questionnaire (JPQ), four different performance estimators were developed. These estimators are functions of the total number of uncommonly effective (ΣUE) and the total number of uncommonly ineffective (ΣUI) incidents of performance observed by the supervisor on each of eight job dimensions characteristic of electronic maintenance activities. The four estimators of human reliability are:

1. Series Reliability Estimate (SRE)

2. Series-Parallel Reliability Estimate (PRE)

3. Geometric Mean Reliability Estimate (GRE)

4. Weighted-Average Reliability Estimate (WRE)

Utilizing the Technical Proficiency Checkout Form as a criterion measure, the validity of each of the four estimators was established. Finally an appropriate statistical analysis of the performance data revealed areas of difficulty with each of the four estimators and suggested modifications required to increase their efficiency.

Findings

The relevant findings of this preliminary investigation of the sample data resulted mainly from an analysis of the distributional properties of the predictor and criterion variables. From an application of Geary's test for normality it was found that only the predictor variable WRE could be termed normally distributed. As a result of this finding, a curvilinear multiple regression technique was applied to a portion of the sample data with an emphasis upon the least-squares analysis resulting from an application of this technique.

A comparison of the multiple correlation coefficients resulting from the curvilinear regression analysis revealed that in every case a straight-line was the best fit to the performance data. The product-moment correlation between the predictor variables (SRE, PRE, GRE, and WRE) and criterion variable were respectively -.069, -.009, .024 and .242 indicating moderate validity on the part of the WRE for appraising the absolute level of technician performance.

Conclusions

Even though the statistical analysis for this report was concerned with the data collected at only one location (Flotilla NINE, San Diego, California), tentative conclusions can be made on the characteristics of the performance evaluators.

The extreme skewness of the distributions of the SRE, PRE, and GRE will probably not be possible to avoid, thus eliminating many convenient analyses of the data. In particular the distribution of the criterion variable as derived from the TPCF is so markedly skewed that no improvement in it is likely with larger sample sizes. The moderate validity of the WRE indicates that the technique of deriving individual performance estimates as a function of supervisory estimates of uncommonly effective and uncommonly ineffective performance is a promising area but requiring further research. Although the other performance estimators did not fare as well as the WRE, it is clear that they could be improved upon if certain areas of difficulty are avoided. It can be concluded that none of these areas of difficulty are insurmountable. In fact they have revealed the appropriate modifications that are needed in order to increase the validity of the performance estimators, e.g., by evaluating only those individuals who actually do work at a high proportion of the job activities.

Research is continuing upon the evaluation of the performance measurement technique with respect to the totality of data collected. It is felt that the larger data base will reveal other aspects of the performance measurement technique, particularly when individual ratings are being considered.

REPORT USE AND EVALUATION

Feedback from consumers concerning the utilization of reports is a vital element in improving products so that they better respond to specific needs. To assist the Chief of Naval Personnel in future planning, it is requested that the use and evaluation form on the reverse of this page be completed and returned. The page is preaddressed and franked; fold in thirds, seal with tape, and mail.

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INTRODUCTION

The purpose of this report is to comment on the data collection effort and initial data reduction methods and analyses that have been performed to date for the ONR work unit entitled Personnel Technology: Relating Individual Performance Effectiveness to Unit and Ship Effectiveness (Office of Naval Research, Project Order Number 2-0046, NR 150-336). The goal of this research project is to provide an empirical basis for assessing the utility to the Navy of a performance measurement technique developed under a prior ONR contract. Under that contract Dr. Arthur I. Siegel, Philip J. Federman, and their associates of Applied Psychological Services, Inc., Wayne, Penn., developed fleet post-training performance evaluative measures which seemed to be of value for eventual widespread implementation within the report - Development of Performance Evaluative Measures: Investigation into and Application of a Fleet Post-Training Performance Evaluative System [12]. Furthermore, the research effort undertaken by Naval Personnel Research and Development Laboratory (NAVPERSRANDLAB) is not only to replicate the efforts of Siegel and Federman [12][1], but also to further research their techniques and similarly related performance measurement techniques.

BACKGROUND

In order to better appreciate the techniques employed in this report, it will be necessary to discuss the development of the performance measurement techniques which were employed by Siegel and Federman [12]. Fundamentally the authors had employed magnitude estimates of functions of critical incidents. In the past this has seemed to be a valid approach to obtain estimates of human performance.

Generally the main problem is to estimate the performance of a particular personnel system as a function of the performance of individuals that are a part of the system. This necessarily reduces personnel system performance estimation to a discussion of estimators of individual performance where individuals are the components of the system. Compounding

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[1] All numbers enclosed in brackets refer to corresponding numbers of documents and publications listed under References.

the individual estimates in a meaningful way will provide estimates of personnel system performance.

Critical Incidents Techniques in Personnel Performance Estimation

Let ΣUE (ΣUI) be the total number of uncommonly effective (uncommonly ineffective) incidents of performance observed by a rater in a certain time period on some individual under observation. Using these functions of critical incidents, previous researchers (see, for example, Whitlock [17], et al.) demonstrated that there is a definite straight line or curvilinear relationship between ΣUE (or the ratio ΣUE/ΣUI) and corresponding performance evaluations. Prior results such as these seemed to leave little doubt that a critical incidents technique to performance evaluation is a valid and useful approach.

Following upon the results of Whitlock, et al., Siegel has further developed and applied the above mentioned techniques to the post-training performance evaluation of individuals in various avionic or electronic ratings in the U. S. Navy. In particular Siegel and Pfieffer [14] suggested that judgments of uncommonly effective and uncommonly ineffective performances possess merit as useful indicators of overall personnel proficiency. The researchers employed magnitude estimates of the number of uncommonly effective and uncommonly ineffective performances relative to a short prior period for avionic personnel. They derived a performance index from the ratio of the sum of uncommonly effective (ΣUE) performances to the sum of uncommonly effective plus the sum of uncommonly ineffective (ΣUI) performances, namely (ΣUE/[ΣUE + ΣUI]). Siegel and Pfeiffer [14] concluded that: (1) magnitude estimates of uncommonly effective and ineffective performances yielded useful data which could form the basis for a personnel subsystem reliability index; (2) the ratio of the sum of uncommonly effective plus the sum of uncommonly ineffective performances yields an index which discriminates in the anticipated direction; and, (3) the obtained avionic personnel subsystem index could be utilized for post-training performance appraisal, personnel placement, and squadron evaluative purposes.

The Job Performance Questionnaire as an Instrument for Obtaining Estimates of ΣUE and ΣUI

The Job Performance Questionnaire (JPQ) is an instrument for providing information on supervisory estimates of ΣUE and ΣUI. Siegel and Federman [12] demonstrated the utility and practicality of a Job Performance Questionnaire (see Appendix A of this paper) for technicians in the eight electronic maintenance ratings (EM, ET, FT, IC, RD, RM, ST, and TM). From an evaluation of 499 technicians in those ratings, the researchers found that the JPQ yields on estimate of the total number of uncommonly effective and uncommonly ineffective incidents of behavior on eight job activity factors. The eight job factors and their definitions are given in

Appendix B. The job activity factors were isolated by Siegel and Schultz [15] and were descriptive of naval avionic electronic maintenance jobs.

It was the contention of Siegel and Federman [12] that estimates of umcommonly effective and of uncommonly ineffective behavior along eight dimensions of job activities could be compounded into a meaningful measure of technician effectiveness. Moreover, the individual technician effectiveness values can be further treated to form effectiveness values for ratings, ships, and squadrons. In particular, for each job activity the reliability ratio ($\Sigma UE/[\Sigma UE + \Sigma UI]$), as employed in the prior reports [12, 14], yields an estimate of the probability of effective performance for the technician and job activity considered. The reliability ratios are then compounded in meaningful ways to provide estimates of individual effectiveness or reliability of on-the-job performance.

Various Procedures for Compounding Reliability Ratios to Estimate Technician Reliability

Employing the reliability ratios defined above, Siegel and Federman [12] have employed those ratios to develop the following reliability estimates:

1) SERIES RELIABILITY ESTIMATE (SRE)

The series reliability measure of total effectiveness for an individual is derived by multiplying individual job activity reliability ratios to yield a total reliability score, i.e.,

$$R_s = r_1 \times r_2 \times \ldots \times r_8$$

where R_s = series reliability[2], and

r_i = ($\Sigma UE/[\Sigma UE + \Sigma UI]$) is the reliability ratio for i^{th} job activity.

It is to be noted that use of the series reliability estimate requires the assumption that performance reliability on each job activity is independent of performance on other job activities.

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[2] It is helpful to note that the series reliability estimate possesses the following properties:

a) for each of the i = 1, ..., 8 job activities $0 \leq r_i \leq 1$, and, therefore,

b) $0 \leq R_s \leq 1$

c) $R_s \leq$ smallest r_i.

2) SERIES-PARALLEL RELIABILITY ESTIMATE (PRE)

It has been stated by Siegel and Federman [12] that "the series and series-parallel reliabilities provide measures of personnel proficiency relative to performance on the entire job (i.e., all eight job activities)." The series-parallel estimate of individual proficiency is defined as:

$$R_p = R_s \times (2 - r_1) \times \ldots \times (2 - r_8)$$

where R_s, $r_i (i = 1, \ldots, 8)$ are defined in 1) above.

This particular estimate tends to provide a more optimistic estimate of individual performance, however, its content validity and derivation is deserving of further development.

3) GEOMETRIC MEAN RELIABILITY ESTIMATE (GRE)

Let r_1^*, r_2^*, r_3^*, and r_4^* be the four highest job activity reliability ratios of the eight reliability ratios for a technician being evaluated. The geometric mean reliability for the technician is defined as:

$$R_s = \sqrt[4]{r_1^* \times r_2^* \times r_3^* \times r_4^*}$$

This particular estimate is an estimate of individual performance that stresses the strong points of an individuals performance. However, it also tends to ignore his weak points and therefore should be used with caution.

Development of a Criterion for Validating Performance Estimators

In order to determine the validity of the above estimates (SRE, PRE, and GRE) in estimating the absolute level of an individual's performance, performance data were collected by Siegel and Federman [12] by means of an evaluative instrument called the Technical Proficiency Checkout Form (TPCF) (see Appendix C of this paper). The TPCF consists of eight job tasks listed in hierarchial order from easiest to most difficult. The eight tasks meet the Guttman requirements for scalability (see, for example, Guttman [9]). Siegel, Schultz, and Lanterman [16], 1964, employed the scale underlying the eight tasks to determine the cutting points for placing avionic petty officers, third class and strikers in one of the three levels of technical proficiency. The three TECHNICAL PROFICIENCY CHECKOUT (TPC) levels are:

Level 1: above desirable
Level 2: below desirable but at least minimally acceptable
Level 3: below minimally acceptable.

The trichotomous division was based on supervisor's judgments of the performance level required for achieving the objectives given in Appendix D of this paper.

In order to facilitate understanding of the procedure for placing an individual in one of the TPC levels, define the function $F_i (i = 1, \ldots, 8)$ as:

$$F_i = \begin{cases} 1 \text{ if the technician is checked out on the } i^{th} \text{ task of the TPCF} \\ 0 \text{ if the technician is not checked out on the } i^{th} \text{ task of the TPCF.} \end{cases}$$

The TECHNICAL PROFICIENCY (TP) score for a technician is then defined as $\sum_{i=1}^{8} F_i$. Finally, in the prior report [16], the procedure for determining the TPC level is given by:

a) add 0.5 to TP score for an individual. Let TP^* be the resultant score.
b) if $TP^* < 3.92$, then TPC level = 3
c) if $3.92 \leq TP^* \leq 5.63$, then TPC level = 2
d) if $TP^* > 5.63$, then TPC level = 1.

In a later study Siegel and Fischl [13] correlated technicians TPC levels with the technicians total scores on a performance test. Employing a triserial correlation coefficient (see, for example, Jaspen [10]) as an estimate of the product-moment correlation, they found a triserial correlation of .40. When corrected for the lack of perfect reliability in the performance test criterion, its value became .74. On the basis of their investigation of the concurrent validity of the TPCF, they concluded that " the Technical Proficiency Checkout Form, previously shown to be reliable and practical, may now be considered to possess a substantial degree of validity for appraising the absolute proficiency level of avionics technicians in the fleet." Finally, Siegel and Federman [12] recorded a triserial correlation of .38 between the TPC level of the technicians evaluated and their Series Reliability Estimate (SRE), concluding there is some basis to believe that the SRE correlates with on-the-job performance.

Main Results of Prior Studies

While there are other results which many of the previous studies have found relative to the post-training performance estimation of technicians involved in fleet electronic maintenance activities, this report has been and will only be concerned with the validity of the

Series Reliability Estimate (SRE), Series-Parallel Reliability Estimate (PRE), Geometric Mean Reliability Estimate (GRE) in estimating on-the-job performance where the TPCF is the primary measure or criterion of on-the-job performance. Some of the more important conclusions of prior reports relative to content validity of the SRE, PRE, and GRE are:

1. Reliability ratios of the form $\Sigma UE/(\Sigma UE + \Sigma UI)$ indicate the probability of effective performance on a particular job activity for the technician being evaluated.

2. The JPQ is an instrument for providing magnitude estimates of ΣUE and ΣUI for each man being evaluated by his immedate supervisor.

3. The TPCF possesses a substantial degree of validity for appraising the absolute level of technician proficiency and may be employed as a criterion for the JPQ.

4. There is some basis (triserial correlation of .38 with TPC level) to believe that the SRE is a good estimator of on-the-job performance.

THE DATA COLLECTION EFFORT

The data collection effort that this report will be concerned with was conducted with ships from Commander, Cruiser-Destroyer Flotilla NINE, Pacific Fleet, during the months of March and April, 1972. The methodology for the data collection required a project coordinator at Destroyer Flotilla NINE to seek the ships (all of which were destroyers) to take part in the project and the assignment of a liaison officer aboard each ship. Essentially the project coordinator served to coordinate the activities of the project researchers of NAVPERSRANDLAB and those of the ship liaison officers. Initially a meeting was arranged between the ship liaison officers and the project researchers by the project coordinator. In the initial meeting the researchers acquainted the liaison officers of the purpose of the project and their subsequent duties in the data collection effort.

A total of 11 ships from Destroyer Flotilla NINE participated in the project with 582 technicians being evaluated by their immediate supervisors. As in the previous report [12], the technicians were in one of the eight electronic ratings EM, ET, FT, IC, RD, RM, ST, and TM.

Data Collection Instruments

The performance evaluation forms that were completed by each supervisor are given in Appendices C, E, and F. In particular the forms were:

a) Job Performance Questionnaire (JPQ) ANSWER SHEET
This form, an example of which is in Appendix E, serves the same purpose as the JPQ of the previous report [12] given in Appendix A of this paper, i.e., to record estimates of the total number of uncommonly effective (ΣUE) and uncommonly ineffective (ΣUI) performances the supervisor has observed on the man he is evaluating.

b) Technical Proficiency Checkout Form (TPCF)
This form is essentially identical to the TPCF used by Siegel and Federman [12] and was discussed in detail in the Bachground section of this report.

c) Personnel Identification Information Form (PIIF)
This form, an example of which is in Appendix F, was concerned with the background data of the man being evaluated. It was completed in part by his supervisor with the administrative officer providing the remaining information.

Results of the Data Collection Effort

All forms were returned in a useable condition with very few errors in completion and little missing data. All of the missing data was concerned with background information as recorded on the PIIF (Appendix F) and in no way influences the results of this report. Finally the PIIF and JPQ ANSWER SHEET, being optical scanning sheets, were reduced to computer cards ready for the subsequent data analysis.

The entire data collection effort briefly discussed above follows essentially the procedure employed in the previous report [12]. Every effort has been made to insure accuracy and correctness of the data analysis to be discussed in the next section. Also, to achieve a similarity in results, every effort has been made to perform a statistical analysis identical to that of the previous report [12]. Where this is not possible or appropriate, the changes or deviations in analysis from that of the previous report [12] will be commented on.

DATA ANALYSIS AND OBSERVATIONS

In order to initiate the data analysis it will be necessary to investigate in some detail a fundamental problem relating to the Series, Series-Parallel, and Geometric Mean Reliability estimates (the SRE, PRE, and GRE respectively).

Cases of Difficulty in Calculating Performance Estimates

The reader will recall, as discussed in the Background section of this report that reliability ratios of the form ($\Sigma UE/[\Sigma UE + \Sigma UI]$) were derived for each man on each of eight job activities and that these ratios were combined in some way to form the SRE, PRE, and GRE. However, the following two cases require the adoption of some convention in order to calculate the reliability ratios:

1) the technician did not work at that job activity, or

2) the technician received $\Sigma UE = 0$ and $\Sigma UI = 0$ by the supervisor, implying that the reliability ratio $\frac{0}{0 + 0}$ is undefined.

By observing the frequency with which such cases occur across all 11 ships, one can determine the extent to which any convention for estimating performance in those cases would effect individual SRE, PRE, and GRE values. A complete discussion of this effect is given in Appendix G and the interested reader is referred to that section for a more detailed account. For now it suffices to say that the above two cases can have a dramatic effect upon the individual performance estimates and that these estimates will be greatly influenced by the convention that is adopted.

The Adoption of a Convention for Estimating Performance in Certain Job Activities

Siegel and Federman [12] chose to employ "the average value for his rating on his ship," on those job activities which the technician did not work at or received $\Sigma UE = 0$ and $\Sigma UI = 0$ by his supervisor. Unfortunately the results of the data collection effort at San Diego indicated that this technique was not feasible for that data. The main reason for this is that on every ship there were ratings for which in some job activities those two cases occured for all men in that rating. In Appendix I is provided a detailed account of this observation for the interested reader.

In order to overcome this problem, the convention adopted in this report was to employ a composite reliability value across all ships for each job activity and rating. Let $\Sigma UE\ (i, j)$ be the sum across all ships of all ΣUE's over all men in the i^{th} rating and j^{th} job activity. Similarily the sum of all ΣUI's is calculated; denote this sum by $\Sigma UI\ (i, j)$. The composite reliability score for the i^{th} rating and j^{th} job activity is defined as

$$R(i,j) = \Sigma UE(i,j)/[\Sigma UE(i,j) + \Sigma UI(i,j)].$$

This particular estimate of job performance provides an "expected" level of effectiveness for a technician in the i^{th} rating and j^{th} job activity (for ships at San Diego). Appendix K gives the resulting composite reliability values ($R(i,j)$) for each rating and job activity. For example, from Appendix K, $R(1,3)$ is the composite reliability value for EM's on job activity number 3 - Electronic Circuit Analysis - and is given by $R(1,3) = .8465$. For definiteness, we state that for all EM's who have not worked at job activity number 3 or who received $\Sigma UE = 0$ and $\Sigma UI = 0$ for that job activity, their reliability ratio for that job activity is given by $r_3 = R(1,3) = .8465$. Similarly such a procedure is employed on the other ratings and job activities.

The composite reliability score is an estimate that can always be derived when many ships are involved, however, in no way does it overcome the implications of the results discussed in Appendix G and their subsequent effect on the estimates SRE, PRE, and GRE.

The Weighted-Average Reliability Estimator

In addition to the three performance estimators (SRE, PRE, and GRE) previously introduced, this report will also discuss an estimate of the form

$$R_w = \sum_{i=1}^{NJ} r_i\ w_i/NJ$$

where, NJ = number of job activities the technician actually worked at

r_i = the reliability ratio for the i^{th} job activity

w_i = weight denoting the importance of the i^{th} job activity in estimating the technician's overall performance

The estimator R_w will be called a Weighted-Average Reliability Estimate (WRE) of technician effectiveness. This estimator

has the desirable property of providing a performance estimate on only the job activities the technician actually worked at during the rating period.[1] By eliminating those job activities the technician did not work at, the WRE yields an estimate of greater utility.[2] Furthermore, it tends to give most (least) importance to job activities which would be more (less) indicative of the technician's overall performance.

<u>Validity of the Performance Estimators as Determined by a Triserial Correlation</u>

A triserial correlation between each of the four estimators (SRE, PRE, GRE, and WRE) and Technical Proficiency Checkout (TPC) level was calculated to determine the validity of each reliability estimator. The associated results are given in Table 1:

TABLE 1

TRISERIAL CORRELATION INFORMATION FOR TECHNICIANS AT SAN DIEGO

	Mean Reliabilities in Each TPC Level			
TPC LEVEL	SRE	PRE	GRE	WRE
1	.3507	.5968	.9308	.6565
2	.3312	.5527	.9194	.5662
3	.4274	.6245	.9225	.5572
TRISERIAL CORRELATIONS	-0.0900	-0.0149	0.0325	.2555

[1] Included within the NJ job activities may be cases where $\Sigma UE = 0$ and $\Sigma UI = 0$. For those cases the composite reliability values (Appendix K) must be used for the reliability ratios. This procedure was previously discussed on page 9.

[2] Appendix L provides a detailed account of the greater utility of the WRE and an explanation of how the weights (w_i, $i=1,\ldots, NJ$) are derived.

Because the triserial correlation coefficient is an estimate of the product-moment correlation, a test of the hypothesis that the triserial correlation coefficient for each estimate is equal to zero is possible (see, for example, Guilford [8]). However, for only the SRE and WRE could this hypothesis be rejected (at the $\alpha = .05$ level of significance), implying that the PRE and GRE are not good linear estimators of the absolute level of technician performance. On the other hand, the triserial correlation of SRE and TPC level (-.09) is significantly different from zero ($\alpha = .05$), but the sign is not in the hoped for positive direction. The resulting triserial correlation of TPC level with WRE was .2555, which was significantly different from zero ($\alpha = .05$) and in the right direction. As such, at this stage of the analysis, it must be concluded that the WRE is the superior type of estimator, even though, in some sense, SRE possesses minimal merit as an estimator.

The Appropriateness of a Triserial Correlation for Associating Performance Estimators with the TPCF

The previous analysis represents essentially the data analysis techniques adopted by Siegel and Federman [12] but now applied to the sample data at San Diego. However, in an attempt to employ a data analysis appropriate to the data, consider the following assumptions that one is inherently making when applying the triserial correlation (see again Jaspen [10]):

a) the segmented variable is basically continuous and normally distributed

b) all the segments which together would form a whole normal distribution are present.

Our attention will be focused on requirement a). Consider the histogram in Appendix N. This is a histogram of all the Technical Proficiency (TP) scores (defined in the Background section of this report) for technicians evaluated at San Diego. Recall that this variable, Technical Proficiency score (TP score), was segmented into one of three levels of technical proficiency. If in fact all the required segments are present, then the histogram in Appendix N represents the entire distribution of the segmented variable, which may be taken as continuous. Clearly this does not seem to represent a normal distribution. For a more valid proof of this statement, Geary's test for normality [7] was

applied to the distribution of TP scores. Geary's test statistic[1] is given by

$$a = \frac{2(\Sigma' - N'\overline{X})}{\sqrt{N\Sigma X^2 - (\Sigma X)^2}}$$

where X represents an observation, $\overline{X}$ the sample mean, N the sample size, Σ' the sum of all observations greater than $\overline{X}$, and N' the number of observations greater than $\overline{X}$. If the null hypothesis is that the underlying distribution is normal, then it has been shown [2] that

$$z = \frac{(a - .7979)\sqrt{N}}{.2123}$$

is approximately normal with mean zero and variance one. In fact a conservative test of the hypothesis that the underlying distribution is normal (at the $\alpha = .05$ level of significance) is given by:

> reject the null hypothesis of normality if
> z is greater than 1.96 or less than -1.96.

When Geary's test statistic was applied to the sample data of TP scores, the resulting test statistic values were

$$a = .8476, \text{ implying } z = 5.6429$$

Therefore, the assumption of normality for TP scores must be rejected and so an application of the triserial correlation is inappropriate for the sample data collected at San Diego.

For future reference, when Geary's test for normality was applied on the distribution of SRE, PRE, GRE, and WRE, the following table was derived:

---

[1] This particular goodness of fit test has several advantages over the usually applied Kolmogorov-Smirnov tests or the well-known Chi-square tests in that, in particular, the population mean and standard deviation need not be precisely known and the test need not be applied just to large samples. Furthermore Geary's test seems to be more sensitive to departures from normality than the other two tests [3, 4, or 11].

TABLE 2

GEARY'S TEST STATISTIC VALUES FOR THE PERFORMANCE ESTIMATORS

	SRE	PRE	GRE	WRE
a	.8747	.8890	.5456	.7876
z	8.726	10.3472	-28.6657	-1.1716

Clearly the only estimator which is indicative of being normally distributed is the WRE. The lack of normality on the part of the other estimators is not necessarily an undesirable feature, but it is true that this exercise does point out yet one more desirable feature of the WRE, namely, its normality. The reader is also referred to the histograms of the frequency of occurrence of the SRE, PRE, and WRE values given in Appendices O, P, and Q with class intervals for the histograms presented in Appendix R.

Curvilinear Regression Analysis as an Alternative to Triserial Correlation

Essentially due to the non-normality of the TP scores, an alternate analysis is suggested in order to determine the degree of association between the predictor variables (SRE, PRE, GRE, and WRE) and criterion variable (TP score). The particular procedure to be employed to achieve this end will be a curvilinear multiple regression procedure. The reader may review this subject in any of the texts that elaborate on the procedure. In particular Draper and Smith [5] give an excellent concise explanation of all the ramifications of this and related observations on regression in general. However, a few remarks on this subject for the purposes of this report have been provided in Appendix S.

The curvilinear regression analysis that will follow is essentially a replication of the technique in Cooley and Lohnes [1]. Throughout this analysis the predictor variable is one of SRE, PRE, GRE, or WRE while the criterion variable is the TP score. The computer program employed in [1] for curvilinear regression is also used in this paper.

Appendices T, U, V, and W of this paper provide computer printouts[1] as are found in [1] but for the predictor and criterion variables of this report. The computer printouts are in terms of "centered" data making maximum use of the correlation matrix. This technique improves the computation of the printout values by minimizing roundoff errors. Table 3 provides the essential information for the curvilinear regression analysis and is taken from the computer printouts given in Appendices T, U, V, and W.

TABLE 3

RESULTS OF THE CURVILINEAR REGRESSION ANALYSIS

Predictor Variable (X)	r_{xy}	linear R^2	linear s^2	quadratic R^2	quadratic s^2	cubic R^2	cubic s^2
SRE	-.069	.005	.002	.007	.002	.072	.002
PRE	-.009	.000	.002	.043	.002	.047	.002
GRE	.024	.001	.002	.003	.002	.004	.002
WRE	.242	.058	.002	.058	.002	.062	.002

(Type of Curve spans linear, quadratic, cubic.)

r_{xy} = product moment correlation between the predictor variable X and the criterion variable Y (TP score)

R^2 = multiple correlation coefficient

s^2 = residual mean square (M.S.)

Consider Table 3[2] and the evaluation of SRE (X) as a predictor of TP score (Y). The product- moment correlation between SRE and TP score

[1] Please disregard the numerous F-ratios which as discussed in Appendix S are of little value for this data.

[2] Note that because the results of Table 3 are in terms of centered data, one must be concerned with the relative magnitude of the residual mean square from attempting to fit a linear model to fitting a cubic model to the data.

is -.069 (not significantly different from zero at the $\alpha = .05$ level). Therefore SRE seems to be non-predictive of TP score (and the absloute level of technician performance). In attempting to fit a linear, quadratic, and cubic model to the data of SRE values and TP scores, the R^2 values were .005, .007, and .072 respectively. However, in view of the fact that the regression mean square(M.S.) does not change from the linear to cubic model, it would be just as well to chose the linear model (particularly since R^2 for the cubic equation is only slightly larger than .005). Therefore, the best regression equation is

$$Y = 5.458 - 0.447X.$$

Because X and Y are essentially independent, the best estimate of Y will always be $\overline{Y}$, the mean of the observed Y values, regradless of the observed SRE. This result is further reflected in noticing that the sample $\overline{Y}$ is 5.284, approximately equal to 5.458 - the Y-intercept of the regression line. Finally one must conclude that the SRE is a very poor estimator of TP score and therefore cannot be held to possess significiant utility for widespread implementation.

Observing the results of Table 3 for the predictor variables PRE and GRE, one will have to draw the same conclusions as the above on SRE. In fact the PRE and GRE seem to be even poorer estimators of TP score than SRE. Only the WRE, with a computer printout for regression given in Appendix W, seems to possess any merit as an estimator of TP score. In particular the product-moment correlation of .242 does offer some hope that the WRE can be associated with on-the-job performance. Because R^2 is essentially the same and the Residual M. S. does not vary, the linear fit would seem to be the best fit to the sample data. The linear regression equation is given by

$$Y = 3.66 + 2.646X$$

where Y is TP score and X is WRE. In conclusion it must be said that WRE possesses modest value as an estimator of absolute technician proficiency. Hopefully further research into this estimator and associated ones will provide a more valid estimator of technician performance as a function of magnitude estimates of critical incidents.

SUMMARY OF RESULTS AND OBSERVATIONS

The data collection effort conducted by NAVPERSRANDLAB at Destroyer Flotilla NINE, Pacific Fleet, involved immediate supervisore evaluating technicians in the eight electronic ratings - EM, ET, FT, IC, RD, RM, ST, and TM. From the evaluations of 582 men at that location predictor

variable information was collected on the JPQ ANSWER SHEET (Appendix E) and criterion variable information was collected on the Technical Proficiency Checkout Form (Appendix C). The following conclusions have been made in this paper relative to four estimators of technician proficiency:

a) The Series Reliability Estimate, the Parallel-Series Reliability Estimate, and the Geometric Mean Reliability Estimate (as predictor variables derived from information on the JPQ ANSWER SHEET) do not seem to be predictive of the absolute level of technician proficiency as deter- by Technical Proficiency (TP) Score (the criterion variable derived from information on the Technical Proficiency Checkout Form). In every case the product-moment correlation coefficient could not be termed significantly different from zero (at the $\alpha = .05$ level). This conclusion was made in view of the results of a curvilinear regression analysis. For each estimator the best least squares fit to the sample data seemed to be a linear fit. Finally in every case the mean of the sample criterion variable (technical proficiency score) is the best estimate of an absolute level of technician proficiency. As such none of these predictor variables seem to estimate absolute technician proficiency and cannot at this stage of the data analysis be held to possess utility for widespread implementation.

b) The Weighted-Average Reliability Estimator possesses moderate validity as an estimator of the absolute level of technician proficiency. The results of the curvilinear regression analysis indicated that a linear equation was the best fit to the sample data. Furthermore, a correlation of .242 with the criterion variable indicates that it possesses a possibility for future use in arriving at estimates of personnel system performance proficiency.

The above results were made under the assumption that the Technical Proficiency Checkout Form possesses a high degree of validity for appraising the absolute level of technician proficiency. This assumption is made here as it was by Siegel and Federman [12]. However, this assumption was verified for technicians in avionic ratings by Siegel and Fischl [13].

Further research in this area will involve a comparison of the above results with a similar statistical analysis applied to the sample data collected at Newport, Rhode Island, and Boston, Mass., in which a total of 367 men were involved. Furthermore, subsequent data analysis will investigate the possibility of whether or not any of the predictor variables can be validly applied to particular ratings, rather than to the population of eight electronic ratings as a whole as this report had done. Finally the possibility of combining worthwhile estimators of electronic ratings performance proficiency in a meaningful way to calculate ship or squadron efficiency will be researched.

APPENDIX A

JOB PERFORMANCE QUESTIONNAIRE

Name of Supervisor__________________________Rating________Ship or Unit________

Instructions to Supervisor. The purpose of this form is to determine the number of effective and ineffective performances you have observed among your men during the past two months. We are only interested in the ***uncommonly effective*** and the ***uncommonly ineffective*** performances.

List below the names of all the men under your supervision who are currently striking for, or in any of the following ratings: DS, EM, ET, FT, IC, MT, RD, RM, ST, TD, TM (AE, AT, AQ, AX). If you supervise more than one of these ratings, please use a separate form for each rating.

Now, considering the fleet electronic maintenance objectives, enter your estimate of the number of uncommonly effective (UE) and uncommonly ineffective (UI) performances during the past two months for each man being rated. Please refer to the definitions lists for the meanings of the JOB ACTIVITIES and of the OBJECTIVES involved.

The first line has been filled in as an example. The supervisor completing the example felt that Peter Smith had ten unusually effective performances and two unusually ineffective performances while performing ***Electronic Circuit Analyses*** when considered against the objectives of fleet electronic maintenance. He also felt that Smith showed two uncommonly effective performances in the area of ***Electrosafety*** and four uncommonly ineffective performances in ***Instruction***.

If a man has ***not*** had an opportunity to perform in a particular area, enter a dash (-); if he has had an opportunity but has not shown any uncommonly effective or ineffective performances, enter a zero (0).

JOB ACTIVITIES	Using Reference Materials		Equipment Operation		Electronic Circuit Analysis		Personnel Relationships		Electro-safety		Instruction		Electro-repair		Electro-cognition	
Name and rating	UE	UI	UE	UI	UE	UI	UE	UI	UE	UI	UE	UI	UE	UI	UE	UI
Peter Smith ST3	—	—	0	0	10	2	0	0	2	0	0	4	0	0	—	—

APPENDIX B

DESCRIPTION OF JOB ACTIVITIES

JOB ACTIVITY	DESCRIPTION

1. <u>Using Reference Materials</u>--includes the following type of activities:

   a. use of supporting reference materials
   b. making out reports

2. <u>Equipment Operation</u>--includes the following type of activity:

   a. operating equipment, electrical and electronics test equipment, and other electronic equipments

3. <u>Electronic Circuit Analysis</u>--includes the following type of activities:

   a. understanding the principles of electronic circuitry
   b. making out failure reports
   c. keeping records of maintenance usage data

4. <u>Personnel Relationships</u>--includes the following type of activity:

   a. supervising the operation, inspection, and maintenance of electronic equipments

5. <u>Electro-safety</u>--includes the following type of activity:

   a. using safety precautions on self and equipment

6. <u>Instruction</u>--includes the following type of activity:

   a. teaching others how to inspect, operate, and maintain electronic equipments

7. <u>Electro-repair</u>--includes the following type of activity:

   a. equipment repair in the shop

8. <u>Electro-cognition</u>--includes the following type of activities:

   a. maintenance and troubleshooting of electronic equipments
   b. use of electronic maintenance reference materials

APPENDIX C

TECHNICAL PROFICIENCY CHECKOUT FORM

NAME OF SUPERVISOR________________________ RATING/RATE______________

FULL NAME OF MAN EVALUATED____

SHIP OR UNIT______________ LOCATION________________ DATE______________

TASK DESCRIPTION	CHECKED OUT	NOT CHECKED OUT
1. Capable of employing safety precautions on most of this unit's equipment with which his rating is concerned.	☐	☐
2. Capable of replacing most of this unit's equipment with which his rating is concerned.	☐	☐
3. Capable of removing most of this unit's equipment with which his rating is concerned.	☐	☐
4. Capable of following block diagrams for most of this unit's equipment with which his rating is concerned.	☐	☐
5. Capable of knowing relationship of equipment to other related equipment with which his rating is concerned.	☐	☐
6. Capable of calibrating most of this unit's equipment with which his rating is concerned.	☐	☐
7. Capable of trouble-shooting/isolated malfunction(s) in most of this unit's equipment with which his rating is concerned.	☐	☐
8. Capable of employing electronic principles involved in maintenance of most of this unit's equipment with which his rating is concerned.	☐	☐

MAKE CERTAIN THERE IS AN "X" IN A BOX OPPOSITE EACH TASK DESCRIPTION

APPENDIX D

MEANINGS OF FLEET ELECTRONICS MAINTENANCE OBJECTIVES

1. Readiness

To maintain efficiently self, subordinate personnel, equipment, and systems in state of readiness consistent with fleet requirements.

2. Performance

To complete any given mission in minimum time with appropriate level of accuracy and reliability.

3. Operation

To obtain optimum system output when equipment is operated, i.e., output characterized by precision and variability appropriate to mission.

4. Safety

To carry out duties with maximum protection for men and equipment consistent with mission.

5. Preparation

To prepare for personnel requirements of present and future equipment, systems, and situations through use of training programs, maintenance of high morale, etc.

APPENDIX E

REMINDER: WHEN TYPING LAYOUT, PLEASE MAKE SURE THE RIBBON IS IN GOOD CONDITION SO THAT YOU WILL HAVE A SHARP, DARK COPY FOR BETTER REPRODUCTION.

J P Q ANSWER SHEET

NAME OF MAN EVALUATED ____________ RATING/RATE ____________

NAME OF SUPERVISOR ____________ SHIP OR UNIT ____________ LOCATION ____________

DATE ____________

Section	(a) UE	(b) UI	(c)
Using Reference Materials	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Equipment Operation	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Electronic Circuit Analysis	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Personnel Relationships	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Electro-safety	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Instruction	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Electro-repair	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3
Electro-cognition	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3

QUESTIONS

(d)	(e)	(f)
1 2 3 4 5	1 2 3 4	1 2 3

Supervisor's Social Security No.

Technician's Social Security No.

FOR OFFICE USE ONLY

Sq.	Ship	Ind. No	TPC
	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	

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APPENDIX F

REMINDER: WHEN TYPING LAYOUT, PLEASE MAKE SURE THE RIBBON IS IN GOOD CONDITION SO THAT YOU WILL HAVE A SHARP, DARK COPY FOR BETTER REPRODUCTION.

PERSONNEL IDENTIFICATION INFORMATION FORM (PIIF)

NAME OF SUPERVISOR ____________ RATING/RATE ______

DATE __________ SHIP OR UNIT __________ LOCATION ______

DIRECTIONS

Use a #2 pencil only. Blacken the answer rectangle completely. Cleanly erase answers you want to change. Erase any stray marks. 'TECHNICIAN' is the man being evaluated.

In the boxes just below, print as much as possible of the TECHNICIAN'S NAME. Start with his last name, print one letter to a box. Leave one box blank, then print his first name; leave another box blank, then his middle name, etc.

a–z	a–z	a–z	a–z	a–z	a–z	a–z	a–z	a–z	a–z	a–z	a–z

FINAL MARK

A School				B School				C School			
0–9	0–9	.0–.9	0–9	0–9	0–9	.0–.9	0–9	0–9	0–9	.0–.9	0–9

CLASS STANDING

0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9

CLASS SIZE

0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9

GCT		ARI		MECH		CLER		Yrs. Ed.	
0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9

Technician's Birthdate

Month	19__	
Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	0–9	0–9

Technician's Months Known by Supervisor		Technician's Months on Current Job Assignment	
0–9	0–9	0–9	0–9

Technician's Months of Active Duty Service

USN		USNR	
0–9	0–9	0–9	0–9

Technician's Rating	Technician's Paygrade
EM	E-1
ET	E-2
FT	E-3
IC	E-4
RD	E-5
RM	E-6
ST	E-7
TM	E-8
	E-9

Technician's Social Security No.

0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9

UTILITY Layout

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OFFICIAL SCANNING FORMS by OPTICAL SCANNING CORPORATION

APPENDIX G

The purpose of this section is to examine the frequency with which the two cases:

1. a technician did not work at a job activity, and

2. a technician received $\Sigma UE = 0$ and $\Sigma UI = 0$,

occured for each rating and job activity across all eleven ships participating in the project. From this one can infer on the extent which any convention for estimating performance in those cases would effect individual SRE, PRE, and GRE values.

Refer to the table in Appendix H. Each square in the table represents the number and proportion of technicians by rating evaluated at San Diego who did not work at a particular job activity or received $\Sigma UE = 0$ and $\Sigma UI = 0$ by their supervisor. Therefore, on job activity Number 1, 10 of the EM's (or 18.5% of the EM's) evaluated at San Diego either do not work at that job activity (Using Reference Materials) or received $\Sigma UE = 0$ and $\Sigma UI = 0$. This, however, may seem a tolerable level of occurence of such cases, but when the proportion of such cases exceeds .33, one should begin to consider whether the performance of some individuals is due more to the convention that must be adopted rather than to the individual's own job effectiveness. Of the 64 squares in the table, 46 squares had one-third or more of the men in some rating falling into the two cases for some job activity, 25 squares had one-half or more of the men in some rating falling into the two cases, and most critically, 6 squares had at least 75% of the men in those cases. In particular the RD and RM ratings were particularly notorious for this type of situation occuring. It is clear in the RD and RM ratings that any convention adopted will probably poorly reflect individual performance and more reflect the effect of the convention. No rating seems to be free of this situation for some job activities, however, some ratings demonstrate this effect for more job activities.

APPENDIX H

NUMBER AND PROPORTION OF MEN WHO DID NOT WORK AT A PARTICULAR JOB ACTIVITY OR RECEIVED $\Sigma UE=0$ AND $\Sigma UI=0$ BY RATING

	RATING							
JOB ACT.	EM	ET	FT	IC	RO	RM	ST	TM
1	10 0.185	26 0.220	43 0.489	6 0.143	31 0.373	32 0.372	23 0.277	5 0.179
2	11 0.204	37 0.314	34 0.386	4 0.095	29 0.349	25 0.291	21 0.253	7 0.250
3	18 0.333	36 0.305	41 0.466	11 0.262	78 0.940	72 0.837	39 0.470	20 0.714
4	20 0.370	60 0.508	60 0.682	20 0.476	49 0.590	50 0.581	47 0.566	8 0.286
5	11 0.204	63 0.534	54 0.614	6 0.143	47 0.566	33 0.384	35 0.422	8 0.286
6	27 0.500	81 0.686	69 0.784	23 0.548	62 0.747	54 0.628	50 0.602	12 0.429
7	9 0.167	36 0.305	49 0.557	3 0.071	82 0.988	81 0.942	38 0.458	18 0.643
8	20 0.370	41 0.347	41 0.466	8 0.190	82 0.988	71 0.826	30 0.361	16 0.571
NUMBER OF MEN IN EACH RATING	54	118	88	42	83	86	83	28

APPENDIX I

This section will be concerned with justifying the hypothesis that no convention can be adopted per ship that will account for those cases in which a technician either does not work at a particular job activity or received $\Sigma UE = 0$ and $\Sigma UI = 0$ from his supervisor. As an example, observe the table in Appendix J. This table is of the same type as that previously reported on for all men at San Diego given in Appendix G, however, it is reporting on only one typical ship out of the eleven ships in the project. For this ship there were 8 (out of 64) instances where those two cases occured for all men in some job activity and rating. The other ten ships demonstrated 16, 7, 8, 10, 13, 12, 5, 5, 5, and 16 (out of 64) such instances. Therefore, it is impossible to form an average estimate (or some composite value) per ship for each rating and job activity based upon the performance of individuals in that rating and job activity who received $\Sigma UE \neq 0$ and/or $\Sigma UI \neq 0$ if in fact no such individuals exist.

APPENDIX J

NUMBER AND PROPORTION OF MEN WHO DID NOT WORK AT A PARTICULAR JOB ACTIVITY OR RECEIVED ΣUE=0 AND ΣUI=0
BY RATING ON A PARTICULAR SHIP AT SAN DIEGO

	RATING							
JOB ACT.	EM	FT	FT	IC	RD	RM	ST	TM
1	4 0.667	9 0.310	5 0.417	0 0.0	0 0.0	9 0.900	0 0.0	0 0.0
2	6 1.000	13 0.448	7 0.583	0 0.0	0 0.0	9 0.900	0 0.0	1 0.077
3	5 0.833	14 0.483	7 0.583	1 0.167	0 0.0	10 1.000	0 0.0	9 0.692
4	6 1.000	18 0.621	10 0.833	3 0.500	0 0.0	9 0.900	0 0.0	5 0.385
5	6 1.000	21 0.724	8 0.667	0 0.0	0 0.0	8 0.800	0 0.0	1 0.077
6	5 0.833	21 0.724	9 0.750	0 0.0	0 0.0	10 1.000	0 0.0	5 0.385
7	5 0.833	11 0.379	12 1.000	1 0.167	0 0.0	9 0.900	0 0.0	9 0.692
8	6 1.000	16 0.552	8 0.667	1 0.167	0 0.0	10 1.000	0 0.0	6 0.462
NUMBER OF MEN IN EACH RATING	6	29	12	6	0	10	0	13

APPENDIX K

COMPOSITE RELIABILITY VALUES FOR TECHNICIANS AT SAN DIEGO

JOB ACTIVITY	RATING EM	ET	FT	IC	RD	RM	ST	TM
1	0.8770	0.6831	0.7160	0.7466	0.9257	0.9310	0.8537	0.7333
2	0.9050	0.7733	0.7802	0.8217	0.9110	0.9497	0.8899	0.8165
3	0.8465	0.6932	0.7340	0.7981	0.9000	1.0000	0.8662	0.8667
4	0.8639	0.5987	0.7890	0.7692	0.9300	0.9671	0.8930	0.7733
5	0.9004	0.7706	0.9107	0.7865	0.9012	0.9712	0.9161	0.7284
6	0.9333	0.8481	0.8435	0.8039	0.9677	0.9877	0.8571	0.8974
7	0.8981	0.7872	0.8701	0.8163	1.0000	1.0000	0.9078	0.8269
8	0.8744	0.7097	0.7771	0.8105	1.0000	0.9949	0.8571	0.7419

APPENDIX L

The purpose of this section is to demonstrate the greater utility of the WRE as an estimator of individual performance. Essentially it is a better type of estimator in that it is not dependent on a convention to be adopted for the case whereby a man did not work at a particular job activity. As such the convention need only provide reliability ratios for those job activities for which the man being evaluated received $\Sigma UE = 0$ and $\Sigma UI = 0$ from his supervisor.

Consider the table in Appendix M. Each square in the table represents a breakdown of the table given in Appendix G into the number (and proportion) of men who did not work at a particular job activity and those men who received $\Sigma UE = 0$ and $\Sigma UI = 0$. For example, on job activity Number 1, 6 (11% of the EM's) received $\Sigma UE = 0$ and $\Sigma UI = 0$ and 4 (7% of the EM's) did not work at that job activity. The composite reliability values need then only be employed on 11% of the men in that rating and job activity rather then on 18.5% of the men as required by the SRE, PRE, and GRE. More significantly, in the case of RD's and RM's for example, at most 52% (as compared to 98% for the SRE, PRE, and GRE) of the men in those ratings derive reliability ratios for some job activities from the composite reliability table. Clearly this is a significant improvement which should improve individual performance estimates. The statistical analysis in the main text of this paper verified this conjecture.

Derivation of the Weights Employed by the WRE

On the JPQ ANSWER SHEET in Appendix E in column (c) for each job activity the following question was answered by the supervisor on the man he is evaluating:

QUESTION (c) Considering this man's overall performance, it is your opinion that the importance of this job activity, as a factor in determining the overall performance of this man, is best described as being:

3. of central and primary importance
2. a significant factor, but of secondary importance
1. of only moderate importance in estimating overall performance
0. of little or no importance

The weights (w_i) for the i^{th} job activity are determined by the formula:

If the supervisor recorded the i^{th} job activity as:

of central and primary importance, the weight $w_i = 1.0$

of secondary importance, the weight $w_i = .75$

of moderate importance, the weight $w_i = .5$

of little or no importance, the weight $w_i = .25$

APPENDIX M

NUMBER AND PROPORTION OF MEN WHO RECEIVED ΣUE=0 AND ΣUI=0

AND NUMBER AND PROPORTION OF MEN WHO DID NOT WORK AT A PARTICULAR JOB ACTIVITY BY RATING

RATING

JOB ACT.	EM		ET		FT		IC		RD		RM		ST		TM	
	NZ	N9	NZ	N9	NZ	N9	NZ	N9	NZ	N9	NZ	N9	NZ	N9	NZ	N9
1	6	4	26	0	38	5	6	0	28	3	16	16	19	4	5	0
	0.111	0.074	0.220	0.0	0.432	0.057	0.143	0.0	0.337	0.036	0.186	0.186	0.229	0.048	0.179	0.0
2	5	6	37	0	33	1	4	0	29	0	18	7	21	0	7	0
	0.093	0.111	0.314	0.0	0.375	0.011	0.095	0.0	0.349	0.0	0.209	0.081	0.253	0.0	0.250	0.0
3	13	5	33	3	37	4	11	0	43	35	35	37	29	10	17	3
	0.241	0.093	0.280	0.025	0.420	0.045	0.262	0.0	0.518	0.422	0.407	0.430	0.349	0.120	0.607	0.107
4	12	8	37	23	45	15	16	4	30	19	20	30	36	11	7	1
	0.222	0.148	0.314	0.195	0.511	0.170	0.381	0.095	0.361	0.229	0.233	0.349	0.434	0.133	0.250	0.036
5	8	3	62	1	53	1	6	0	43	4	26	7	34	1	7	1
	0.148	0.056	0.525	0.008	0.602	0.011	0.143	0.0	0.518	0.048	0.302	0.081	0.410	0.012	0.250	0.036
6	18	9	58	23	45	24	17	6	34	28	22	32	29	21	9	3
	0.333	0.167	0.492	0.195	0.511	0.273	0.405	0.143	0.410	0.337	0.256	0.372	0.349	0.253	0.321	0.107
7	4	5	35	1	40	9	3	0	30	52	31	50	25	13	17	1
	0.074	0.093	0.297	0.008	0.455	0.102	0.071	0.0	0.361	0.627	0.360	0.581	0.301	0.157	0.607	0.036
8	11	9	41	0	37	4	8	0	32	50	27	44	21	9	13	3
	0.204	0.167	0.347	0.0	0.420	0.045	0.190	0.0	0.386	0.602	0.314	0.512	0.253	0.108	0.464	0.107

NUMBER OF MEN IN EACH RATING
54 118 88 42 83 86 83 28

NZ = NUMBER AND PROPORTION OF MEN WHO RECEIVED ΣUE=0 AND ΣUI=0 IN THAT JOB ACTIVITY AND RATING

N9 = NUMBER AND PROPORTION OF MEN WHO DID NOT WORK AT THAT JOB ACTIVITY IN THAT RATING

APPENDIX N

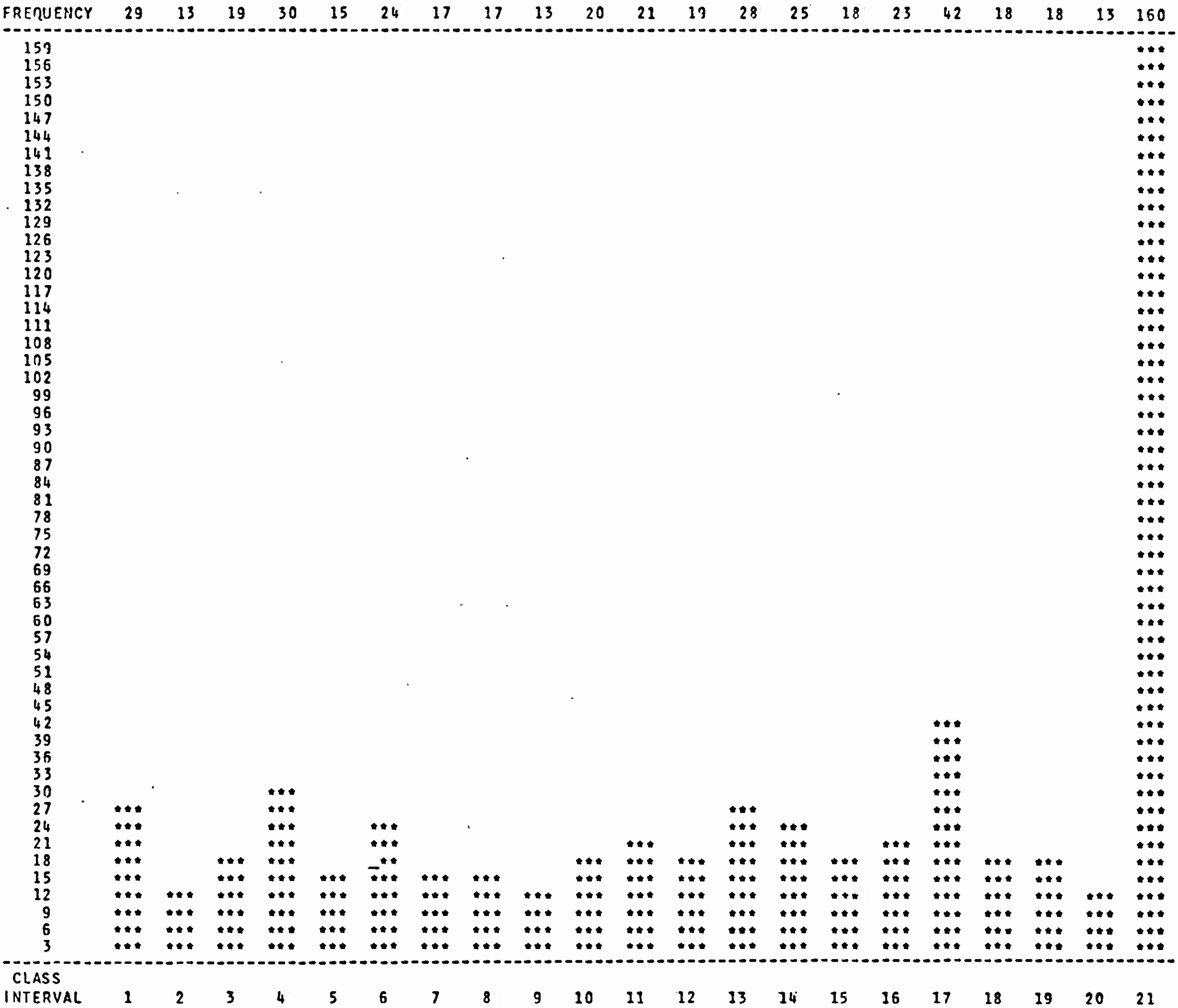
```
                 HISTOGRAM OF TP SCORES FOR SAN DIEGO CAL

FREQUENCY       11    37    46    51    52    81    92    68   144
------------------------------------------------------------------
   144                                                        ****
   141                                                        ****
   138                                                        ****
   135                                                        ****
   132                                                        ****
   129                                                        ****
   126                                                        ****
   123                                                        ****
   120                                                        ****
   117                                                        ****
   114                                                        ****
   111                                                        ****
   108                                                        ****
   105                                                        ****
   102                                                        ****
    99                                                        ****
    96                                                        ****
    93                                                        ****
    90                                            ****        ****
    87                                            ****        ****
    84                                            ****        ****
    81                                      ****  ****        ****
    78                                      ****  ****        ****
    75                                      ****  ****        ****
    72                                      ****  ****        ****
    69                                      ****  ****        ****
    66                                      ****  ****  ****  ****
    63                                      ****  ****  ****  ****
    60                                      ****  ****  ****  ****
    57                                      ****  ****  ****  ****
    54                                      ****  ****  ****  ****
    51                          ****  ****  ****  ****  ****  ****
    48                          ****  ****  ****  ****  ****  ****
    45                    ****  ****  ****  ****  ****  ****  ****
    42                    ****  ****  ****  ****  ****  ****  ****
    39                    ****  ****  ****  ****  ****  ****  ****
    36              ****  ****  ****  ****  ****  ****  ****  ****
    33              ****  ****  ****  ****  ****  ****  ****  ****
    30              ****  ****  ****  ****  ****  ****  ****  ****
    27              ****  ****  ****  ****  ****  ****  ****  ****
    24              ****  ****  ****  ****  ****  ****  ****  ****
    21              ****  ****  ****  ****  ****  ****  ****  ****
    18              ****  ****  ****  ****  ****  ****  ****  ****
    15              ****  ****  ****  ****  ****  ****  ****  ****
    12              ****  ****  ****  ****  ****  ****  ****  ****
     9        ****  ****  ****  ****  ****  ****  ****  ****  ****
     6        ****  ****  ****  ****  ****  ****  ****  ****  ****
     3        ****  ****  ****  ****  ****  ****  ****  ****  ****
------------------------------------------------------------------
TP SCORE         0     1     2     3     4     5     6     7     8


EACH **** EQUALS  3 POINTS
```

APPENDIX O

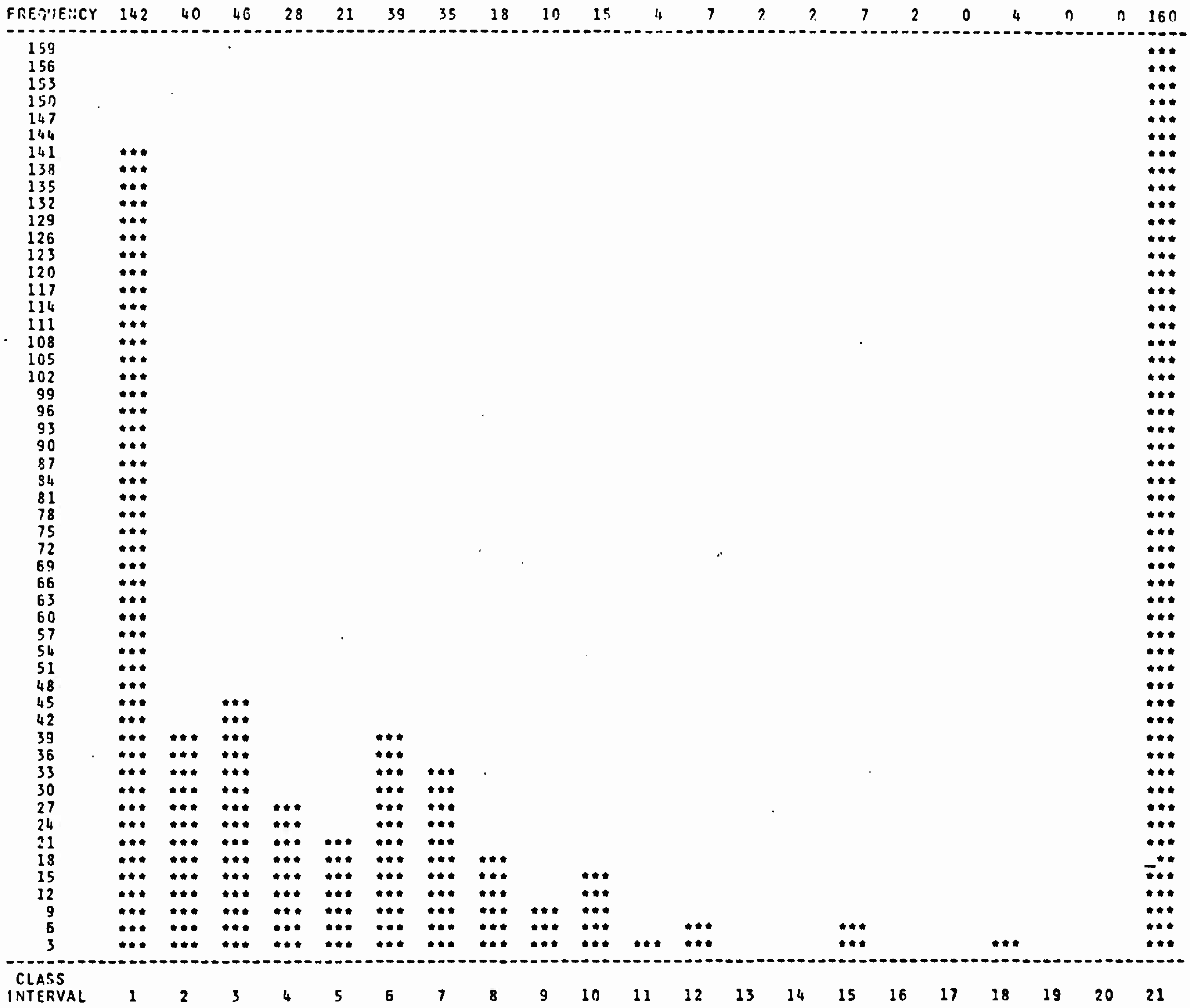
HISTOGRAM OF SERIES RELIABILITY ESTIMATES (SRE) FOR TECHNICIANS AT SAN DIEGO, CALIFORNIA



EACH *** EQUALS 3 POINTS

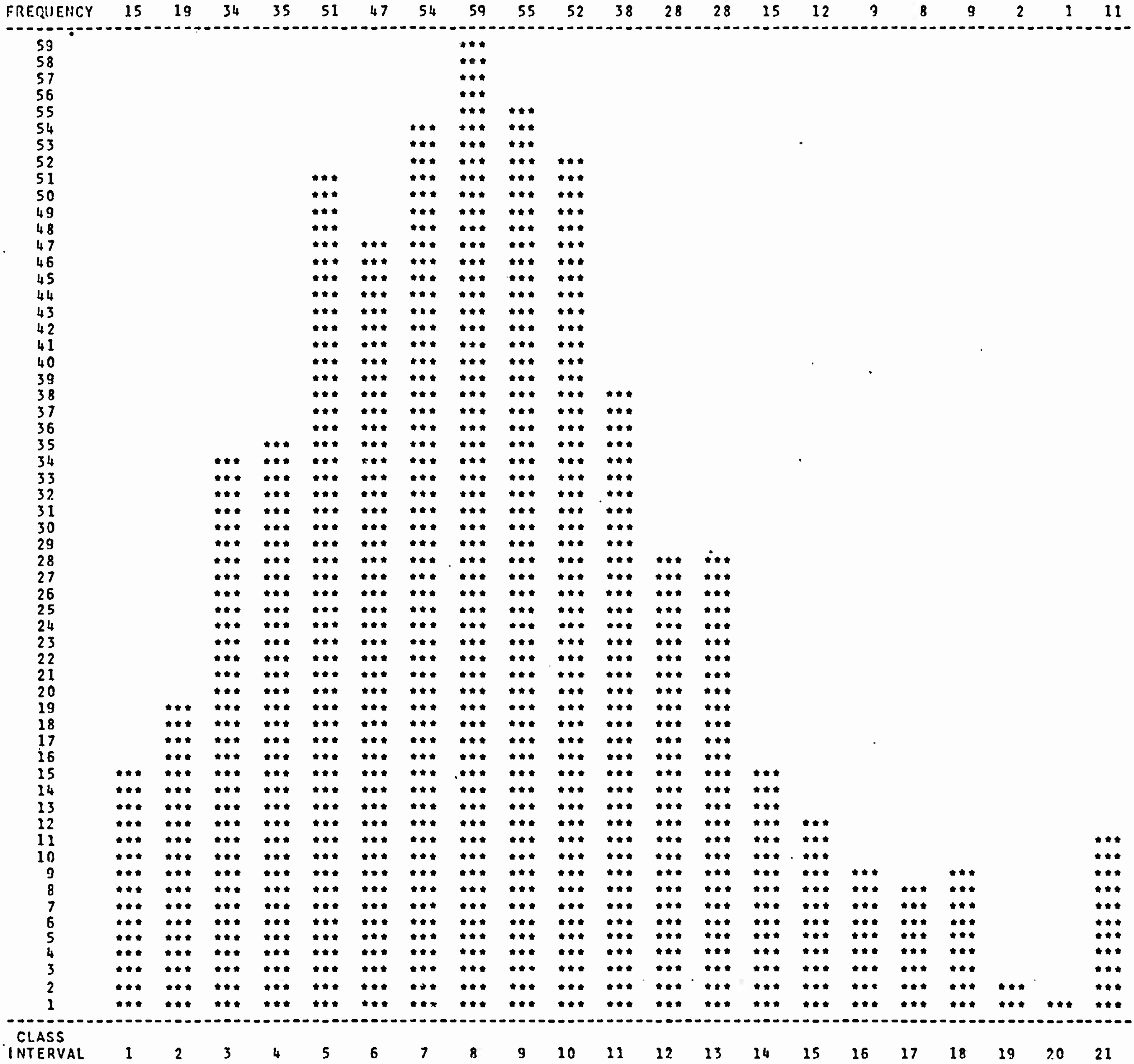
APPENDIX P

HISTOGRAM OF SERIES-PARALLEL RELIABILITY ESTIMATES (PRE) FOR TECHNICIANS AT SAN DIEGO, CALIFORNIA



EACH *** EQUALS 3 POINTS

HISTOGRAM OF WEIGHTED-AVERAGE RELIABILITY ESTIMATES (WRE) FOR TECHNICIANS AT SAN DIEGO, CALIFORNIA



EACH *** EQUALS 1 POINT

APPENDIX R

Class Intervals for Histograms of Various Reliability Estimates

CLASS INTERVAL NUMBER	CLASS INTERVAL
1	[.96, 1.0]
2	[.91, .96)
3	[.86, .91)
4	[.81, .86)
5	[.76, .81)
6	[.71, .76)
7	[.66, .71)
8	[.61, .66)
9	[.56, .61)
10	[.51, .56)
11	[.46, .51)
12	[.41, .46)
13	[.36, .41)
14	[.31, .36)
15	[.26, .31)
16	[.21, .26)
17	[.16, .21)
18	[.11, .16)
19	[.06, .11)
20	[.01, .06)
21	[.00, .01)

The class interval [a, b) is defined to be the set of all numbers x such that $a \leq x < b$.

APPENDIX S

Let Y be a criterion variable and X the predictor variable. If N is the number of observations on each of X and Y, then $\underset{\sim}{Y}' = [Y_1, \ldots, Y_N]$ is the row vector of observations on Y. For a given matrix A, A' will be the transpose of A. In particular one wishes to establish a linear regression equation for a particular response Y in terms of the variables X, X^2, X^3, i.e. it is desirable to establish which of the three power curves, linear, quadratic, or cubic:

$$Y = \beta_o + \sum_{i=1}^{p} \beta_i X^i \qquad p = 1, 2, \underline{or}\ 3$$

best fit the data obtained on X and Y. In matrix notation the above equations, in terms of the sample observation vectors, can be expressed as:

$$\underset{\sim}{Y} = \underset{\sim}{X}\underset{\sim}{\beta} + E$$

where $\underset{\sim}{Y}$ was defined above. The matrix $\underset{\sim}{X} = [J, \underset{\sim}{X}_1, \underset{\sim}{X}_2, \underset{\sim}{X}_3]$ where $J' = [1, \ldots, 1]_{1xN}$, $\underset{\sim}{X}_i' = [X_1^i, \ldots, X_N^i]$ for i = 1, 2, or 3 and therefore $\underset{\sim}{X}_1$ is an N x 1 column vector of observations. $\underset{\sim}{\beta}' = [\beta_o, \ldots, \beta_p]$, the vector of p + 1 regression parameters. $E' = [e_1, \ldots, e_N]$ is the vector of errors due to lack of fit in the particular linear model. One wishes to estimate $\underset{\sim}{\beta}$ such that the error sum of squares E'E is minimized. In particular a <u>least squares estimate</u> $\tilde{\underset{\sim}{\beta}}$ of $\underset{\sim}{\beta}$ is given by

$$\tilde{\underset{\sim}{\beta}} = (\underset{\sim}{X}'\underset{\sim}{X})^{-1}\underset{\sim}{X}'\underset{\sim}{Y}$$

provided the square matrix $\underset{\sim}{X}'\underset{\sim}{X}$ is nonsingular and the regression problem has been properly expressed. The usual assumption one makes is that E' is distributed with mean $[0, \ldots, 0]_{1xN}$ and variance-covariance matrix $\sigma^2 I$ where I is the identity matrix. σ^2 is called the common error variance of the observations. The assumption of normality of the error vector E is not required in order to obtain the least square estimates for any of the parameters in the regression equation. Because any assumption of normality for E implies that the observations on Y or X are normally distributed, this paper will be concerned with only least squares estimates. One cannot discuss normality on X or Y because of prior results (TABLE 2) where it was shown that the distribution of TP scores, SRE, PRE, and GRE are not normally distributed. Therefore, it is imperative that the reader be aware that while the assumption of E being normally distributed is <u>not</u> required in order to obtain $\tilde{\underset{\sim}{\beta}}$, it is required in order to make tests of hypothesis, as contained in an Analysis of Variance Table, which depend on the assumption of normality. These tests are the usual t- or F-tests and they <u>cannot be validly</u> applied to the sample data obtained at San Diego.

A Least Squares Analysis of the Sample Data

It is possible that a least squares analysis can be attempted independently of the distributional properties of the criterion and predictor variables. For a particular predictor variable (X) and criterion variable (Y), the square of the multiple correlation coefficient (R^2) provides a measure of the degree to which a particular regression model explains variation in the data. R^2 is defined as

$$R^2 = \frac{\text{Sum of squares due to regression - Sum of squares due to } \beta_0}{\text{Total (corrected) sum of squares}}$$

$$= (\tilde{\beta}'X'Y - \frac{Y'Y}{N})/(Y'Y - \frac{Y'Y}{N})$$

It should be clear that the larger R^2 is, the better the fitted equation explains the variation in the data. Furthermore, $0 \leq R^2 \leq 1$, and therefore $R^2 = 1$ implies a perfect fit. However, there are a few problems with this approach (see, for example, Draper and Smith [5] page 63). Rather one must weight the value of R^2 with the least squares estimate (s^2) of the common error variance (σ^2) where

$$s^2 = \text{residual mean square}$$

$$= (Y'Y - \frac{Y'Y}{N})/(N - p - 1)$$

Of course, the smaller s is for a particular model under consideration the better the model fits the data. Therefore, the approach is to weight increases in R^2 with decreases in s in order to arrive at the best least squares model for the data.

```
THE PREDICTOR VARIABLE(X) IS SRE, AND THE CRITERION VARIABLE(Y) IS TP SCORE.

TEST MEANS AND STANDARD DEVIATIONS
 1      X          0.365       0.335
 2   SQUAR         0.245       0.307
 3   X CUBE        0.188       0.285
 4      Y          5.284       2.329
CORRELATION MATRIX
 1      X          1.000       0.957        0.897       -0.069
 2   SQUAR         0.957       1.000        0.985       -0.080
 3   X CUBE        0.897       0.985        1.000       -0.063
 4      Y         -0.069      -0.080       -0.063        1.000
===============================================================================
FIRST, SECOND, AND THIRD DEGREE POLYNOMIALS.
===============================================================================
MULTIPLE R SQUARE =     0.005
MULTIPLE R =     0.069
N.D.F.1 =    1
N.D.F.2 =         580
F FOR ANALYSIS OF VARIANCE ON R =        2.740
BETA WEIGHTS
 -0.069
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1      X         0.005      -1.000
SQUARED BETA WEIGHTS
  0.005
B WEIGHTS
 -0.477
INTERCEPT CONSTANT =      5.458
===============================================================================
MULTIPLE R SQUARE =     0.007
MULTIPLE R =     0.084
N.D.F.1 =    2
N.D.F.2 =         579
F FOR ANALYSIS OF VARIANCE ON R =        2.068
BETA WEIGHTS
  0.093  -0.169
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1      X        -0.006      -0.814
   2   SQUAR        0.013      -0.947
SQUARED BETA WEIGHTS
  0.009   0.029
B WEIGHTS
  0.648  -1.282
INTERCEPT CONSTANT =      5.361
===============================================================================
MULTIPLE R SQUARE =     0.072
MULTIPLE R =     0.268
N.D.F.1 =    3
N.D.F.2 =         578
F FOR ANALYSIS OF VARIANCE ON R =       14.953
BETA WEIGHTS
  1.814  -4.972    3.205
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1      X        -0.124      -0.256
   2   SQUAR        0.397      -0.298
   3   X CUBE      -0.201      -0.234
SQUARED BETA WEIGHTS
  3.291  24.718  10.270
B WEIGHTS
 12.627 -37.742  26.158
INTERCEPT CONSTANT =      5.017


ANOVA TABLE FOR POLYNOMIALS
===============================================================================
 REDUCTION DUE TO LINEAR FIT, WITH 1 DF =       0.005
 RESIDUAL S.S. =         0.995  DF =      580  RESIDUAL M.S. =        0.002
F FOR LINEAR FIT =       2.740
===============================================================================

 REDUCTION DUE TO GENERAL QUADRATIC FIT WITH DF 2. =         0.007
REDUCTION M.S. =         0.004
 RESIDUAL S.S. =         0.993  DF =      579  RESIDUAL M.S. =        0.002
F FOR QUADRATIC FIT =      2.068
REDUCTION DUE TO QUADRATIC TERM ALONE, WITH 1 DF. =        0.002
F FOR QUADRATIC TERM ALONE =       1.395
===============================================================================

REDUCTION DUE TO GENERAL CUBIC FIT WITH DF 3. =        0.072
REDUCTION M.S. =         0.024
 RESIDUAL S.S. =         0.928  DF =      578  RESIDUAL M.S. =        0.002

F FOR GENERAL CUBIC FIT =    14.853
REDUCTION DUE TO CUBIC TERM ALONE WITH 1 DF = ,       0.064
F FOR CUBIC TERM ALONE =  40.141
===============================================================================
```

```
**********************************************************************
POLYNOMIAL FITTING FOR    2 VARIABLES-PRE AND TP SCORE.    582 OBSERVATIONS,
```

APPENDIX U

```
THE PREDICTOR VARIABLE(X) IS PRE, AND THE CRITERION VARIABLE(Y) IS TP SCORE,


TEST MEANS AND STANDARD DEVIATIONS
 1       X            0,594       0,399
 2    SQUAR           0.512       0,388
 3    X CUBE          0,454       0,384
 4       Y            5,284       2,329
CORRELATION MATRIX
 1       X            1,000       0,974       0,930      -0,009
 2    SQUAR           0,974       1,000       0,989      -0,056
 3    X CUBE          0,930       0,989       1,000      -0,087
 4       Y           -0,009      -0,056      -0,087       1,000
**********************************************************************
FIRST, SECOND, AND THIRD DEGREE POLYNOMIALS,
**********************************************************************
MULTIPLE R SQUARE =     0,000
MULTIPLE R =     0,009
N,D,F,1 =    1
N,D,F,2 =          580
F FOR ANALYSIS OF VARIANCE ON R =         0,047
BETA WEIGHTS
 -0,009
CONTRIBUTIONS TO MULTIPLE CORRELATION
    AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
 1       X            0,000      -1,000
SQUARED BETA WEIGHTS
  0,000
B WEIGHTS
 -0,052
INTERCEPT CONSTANT =        5,315
**********************************************************************
MULTIPLE R SQUARE =     0,043
MULTIPLE R =     0,207
N,D,F,1 =    2
N,D,F,2 =          579
F FOR ANALYSIS OF VARIANCE ON R =        13,014
BETA WEIGHTS
  0,884  -0,917
CONTRIBUTIONS TO MULTIPLE CORRELATION
    AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
 1       X           -0,008      -0,043
 2    SQUAR           0,051      -0,268
SQUARED BETA WEIGHTS
  0,781   0,840
B WEIGHTS
  5,154  -5,496
INTERCEPT CONSTANT =        5,035
**********************************************************************
MULTIPLE R SQUARE =     0,047
MULTIPLE R =     0,217
N,D,F,1 =    3
N,D,F,2 =          578
F FOR ANALYSIS OF VARIANCE ON R =         9,492
BETA WEIGHTS
 -0,053   1,444  -1,465
CONTRIBUTIONS TO MULTIPLE CORRELATION
    AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
 1       X            0,000      -0,041
 2    SQUAR          -0,080      -0,257
 3    X CUBE          0,127      -0,399
SQUARED BETA WEIGHTS
  0,003   2,086   2,147
B WEIGHTS
 -0,307   8,660  -8,881
INTERCEPT CONSTANT =        5,072


  ANOVA TABLE FOR POLYNOMIALS
**********************************************************************
  REDUCTION DUE TO LINEAR FIT, WITH 1 DF =        0,000
  RESIDUAL S,S, =          1,000   DF =      580   RESIDUAL M,S, =        0,002
F FOR LINEAR FIT =      0,047
**********************************************************************

  REDUCTION DUE TO GENERAL QUADRATIC FIT WITH DF 2, =         0,043
REDUCTION M,S, =          0,022
  RESIDUAL S,S, =          0,957   DF =      579   RESIDUAL M,S, =        0,002
F FOR QUADRATIC FIT =     13,014
REDUCTION DUE TO QUADRATIC TERM ALONE, WITH 1 DF, =        0,043
F FOR QUADRATIC TERM ALONE =     25,979
**********************************************************************

REDUCTION DUE TO GENERAL CUBIC FIT WITH DF 3, =        0,047
REDUCTION M,S, =          0,016
  RESIDUAL S,S, =          0,953   DF =      578   RESIDUAL M,S, =        0,002

F FOR GENERAL CUBIC FIT =      9,492
REDUCTION DUE TO CUBIC TERM ALONE WITH 1 DF = ,       0,004
F FOR CUBIC TERM ALONE =    2,345
**********************************************************************
```

```
THE PREDICTOR VARIABLE(X) IS GRE, AND THE CRITERION VARIABLE(Y) IS TP SCORE,


TEST MEANS AND STANDARD DEVIATIONS
  1       X            0,926         0,156
  2    SQUAR           0,882         0,186
  3   X CUBE           0,845         0,217
  4       Y            5,284         2,329
CORRELATION MATRIX
  1       X            1,000         0,958         0,897         0,024
  2    SQUAR           0,958         1,000         0,985         0,008
  3   X CUBE           0,897         0,985         1,000        -0,001
  4       Y            0,024         0,008        -0,001         1,000
==========================================================================
FIRST, SECOND, AND THIRD DEGREE POLYNOMIALS,
==========================================================================
MULTIPLE R SQUARE =     0,001
MULTIPLE R =     0,024
N,D,F,1 =    1
N,D,F,2 =         580
F FOR ANALYSIS OF VARIANCE ON R =        0,326
BETA WEIGHTS
  0,024
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1        X         0,001        1,000
SQUARED BETA WEIGHTS
  0,001
B WEIGHTS
  0,353
INTERCEPT CONSTANT =      4,957
==========================================================================
MULTIPLE R SQUARE =     0,003
MULTIPLE R =     0,058
N,D,F,1 =    2
N,D,F,2 =         579
F FOR ANALYSIS OF VARIANCE ON R =        0,982
BETA WEIGHTS
  0,202  -0,186
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1        X         0,005        0,408
   2    SQUAR        -0,001        0,130
SQUARED BETA WEIGHTS
  0,041   0,034
B WEIGHTS
  3,003  -2,320
INTERCEPT CONSTANT =      4,549
==========================================================================
MULTIPLE R SQUARE =     0,004
MULTIPLE R =     0,066
N,D,F,1 =    3
N,D,F,2 =         578
F FOR ANALYSIS OF VARIANCE ON R =        0,837
BETA WEIGHTS
  0,729  -1,584   0,936
CONTRIBUTIONS TO MULTIPLE CORRELATION
   AND REGRESSION FACTOR LOADINGS,  2ND COLUMN)
   1        X         0,017        0,360
   2    SQUAR        -0,012        0,115
   3   X CUBE        -0,001       -0,017
SQUARED BETA WEIGHTS
  0,532   2,510   0,821
B WEIGHTS
 10,859 -19,791   9,719
INTERCEPT CONSTANT =      4,474



 ANOVA TABLE FOR POLYNOMIALS
==========================================================================
 REDUCTION DUE TO LINEAR FIT, WITH 1 DF =         0,001
 RESIDUAL S,S, =         0,999  DF =      580  RESIDUAL M,S, =        0,002
F FOR LINEAR FIT =     0,326
==========================================================================

 REDUCTION DUE TO GENERAL QUADRATIC FIT WITH DF 2, =        0,003
REDUCTION M,S, =         0,002
 RESIDUAL S,S, =         0,997  DF =      579  RESIDUAL M,S, =        0,002
F FOR QUADRATIC FIT =     0,982
REDUCTION DUE TO QUADRATIC TERM ALONE, WITH 1 DF, =        0,003
F FOR QUADRATIC TERM ALONE =     1,638
==========================================================================

REDUCTION DUE TO GENERAL CUBIC FIT WITH DF 3, =        0,004
REDUCTION M,S, =         0,001
 RESIDUAL S,S, =         0,996  DF =      578  RESIDUAL M,S, =        0,002

F FOR GENERAL CUBIC FIT =     0,837
REDUCTION DUE TO CUBIC TERM ALONE WITH 1 DF = ,        0,001
F FOR CUBIC TERM ALONE =     0,548
==========================================================================
```

```
POLYNOMIAL FITTING FOR    2 VARIABLES-WRE AND TP SCORE,   582 OBSERVATIONS,
```

APPENDIX W

```
THE PREDICTOR VARIABLE(X) IS WRE, AND THE CRITERION VARIABLE(Y) IS TP SCORE,


TEST MEANS AND STANDARD DEVIATIONS
 1       X           0,611        0,213
 2    SQUAR          0,418        0,240
 3    X CUBE         0,305        0,239
 4       Y           5,286        2,329
CORRELATION MATRIX
 1       X           1,000        0,967        0,915        0,242
 2    SQUAR          0,967        1,000        0,986        0,231
 3    X CUBE         0,915        0,986        1,000        0,213
 4       Y           0,242        0,231        0,213        1,000
=====================================================================
FIRST, SECOND, AND THIRD DEGREE POLYNOMIALS,
=====================================================================
MULTIPLE R SQUARE =     0,058
MULTIPLE R =      0,242
N,D,F,1 =     1
N,D,F,2 =           580
F FOR ANALYSIS OF VARIANCE ON R =       35,928
BETA WEIGHTS
  0,242
CONTRIBUTIONS TO MULTIPLE CORRELATION
      AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
   1       X          0,058        1,000
SQUARED BETA WEIGHTS
  0,058
B WEIGHTS
  2,646
INTERCEPT CONSTANT =       3,667
=====================================================================
MULTIPLE R SQUARE =     0,058
MULTIPLE R =      0,242
N,D,F,1 =     2
N,D,F,2 =           579
F FOR ANALYSIS OF VARIANCE ON R =       17,962
BETA WEIGHTS
  0,277   -0,037
CONTRIBUTIONS TO MULTIPLE CORRELATION
      AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
   1       X          0,067        0,999
   2    SQUAR        -0,009        0,956
SQUARED BETA WEIGHTS
  0,077    0,001
B WEIGHTS
  3,038   -0,358
INTERCEPT CONSTANT =       3,577
=====================================================================
MULTIPLE R SQUARE =     0,062
MULTIPLE R =      0,250
N,D,F,1 =     3
N,D,F,2 =           578
F FOR ANALYSIS OF VARIANCE ON R =       12,839
BETA WEIGHTS
 -0,258    1,382   -0,914
CONTRIBUTIONS TO MULTIPLE CORRELATION
      AND REGRESSION FACTOR LOADINGS,   2ND COLUMN)
   1       X         -0,062        0,966
   2    SQUAR         0,319        0,924
   3    X CUBE       -0,194        0,851
SQUARED BETA WEIGHTS
  0,067    1,909    0,835
B WEIGHTS
 -2,829   13,380   -8,888
INTERCEPT CONSTANT =       4,124


  ANOVA TABLE FOR POLYNOMIALS
=====================================================================
  REDUCTION DUE TO LINEAR FIT, WITH 1 DF =        0,058
  RESIDUAL S,S, =          0,942   DF =       580   RESIDUAL M,S, =        0,002
F FOR LINEAR FIT =     35,928
=====================================================================

  REDUCTION DUE TO GENERAL QUADRATIC FIT WITH DF 2, =         0,058
REDUCTION M,S, =           0,029
  RESIDUAL S,S, =          0,942   DF =       579   RESIDUAL M,S, =        0,002
F FOR QUADRATIC FIT =    17,962
REDUCTION DUE TO QUADRATIC TERM ALONE, WITH 1 DF, =        0,000
F FOR QUADRATIC TERM ALONE =      0,055
=====================================================================

REDUCTION DUE TO GENERAL CUBIC FIT WITH DF 3, =        0,062
REDUCTION M,S, =           0,021
  RESIDUAL S,S, =          0,938   DF =       578   RESIDUAL M,S, =        0,002

F FOR GENERAL CUBIC FIT =     12,839
REDUCTION DUE TO CUBIC TERM ALONE WITH 1 DF = ,       0,004
F FOR CUBIC TERM ALONE =     2,499
=====================================================================
```

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13. ABSTRACT

The purpose of this research effort is to validate the utility and effectiveness of a unique human performance measurement technique developed under ONR contract (N0001467C0107). Performance data on eight Navy ratings was collected from ships of LANTFLT and PACFLT. This report is the first in a series of technical reports on the statistical analysis of that data. In particular, a statistical analysis is provided on performance related data for electronic maintenance personnel sampled from 11 ships of CRUDESFLOT NINE, San Diego, California. Four different performance estimators, as functions of critical incidents, are evaluated with respect to a performance criteria. A detailed explanation of the distributional properties of the performance estimators is presented and an explanation of the factors that lead to the adoption of a curvilinear regression analysis for analysis of the data is discussed.

The results of the statistical analysis indicated that a certain combination of the performance data possessed moderate validity for measuring the absolute level of technician performance. Detailed analysis of the performance data also identified the areas of difficulty that have to be avoided in order to improve upon the validity of each of the performance estimators. These and other preliminary results indicate that the technique possesses merit for further development and research. The Naval Personnel Research and Development Laboratory is continuing research on this technique with respect to the totality of data collected.

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